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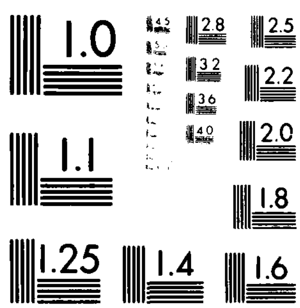

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TRANSACTIONS OF THE SCIENTIFIC-RESEARCH INSTITUTE
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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

AN INVESTIGATION OF THE ELECTROMAGNETIC WAVES WHICH OCCUR DURING THE ACCELERATION OF AN ELECTRON BEAM IN A BETATRON

V. A. Moskalev, Yu. A. Gromov, A. V. Tsimbalist, V. G. Shestakov

The purpose of this work is the investigation of electromagnetic waves which occur during acceleration in a betatron with an intensive electron beam. There may be several reasons for their occurrence:

1. The advent of an effect of a negative mass (longitudinal instability) [1]. In this case the oscillation frequency will be determined by the relation

$$f = mf_c ,$$

where m = 1, 2, ..., 5 is the number of bunches; f_0 is the frequency of the electrons' revolution.

2. Coherent transverse vibrations of the beam.

3. Transverse vibrations of the beam's center of gravity (dipole oscillations) [2]. In this case the frequency

$$f = (m + \nu_c) f_0 ,$$

will be generated where ν_0 = 0.69 is the mean frequency of betatron oscillations.

4. Quadrupole oscillations, when first the vertical and then the radial dimensions of the beam are increased. A frequency [3] of

$$f = (m \pm 2\nu_0) f_0 .$$

will be generated.

5. The various plasma effects due to ionization of residual gas [4].

6. Synchrotron radiation [5]. Resonance effects due to the accelerating chamber's construction and the presence of dissipative elements in it.

The investigated betatron has the following basic parameters: a radius of equilibrium orbit r_0 = 27 cm, an injection energy of E_i = 250 keV, a maximum energy of the accelerated electrons E_{max} = = 25 MeV, a frequency of electron revolution at the injection energy (r_0 = 27 cm) of f_{0L} = 123 MHz and at the maximum energy $f_{0\ max}$ = 177 MHz the number of accelerated particles is $N_{yck} = 4 \cdot 10^{11}$.

The calculations show that electromagnetic waves with a frequency from several dozen up to 10^3 MHz [6] should occur in an accelerating chamber of such a betatron upon longitudinal instability and dipole and quadrupole oscillations of a beam.

Residual gas (a working pressure of $3 \cdot 10^{-6}$ mm Hg) may be highly ionized by a high-power electron beam in an accelerating chamber of a betetron. In the presence of a magnetic field this creates favorable conditions for the occurrence of localized sources of plasma which may be the source of radio-frequency radiation.

The frequency of the investigated unit's synchrotron radiation is in a range of from $1.77 \cdot 10^8$ Hz at E_i to $2 \cdot 10^{13}$ Hz at E_{max}. The lower limit of this range corresponds with wavelengths of the meter band (1.7 m) and the upper limit corresponds to infrared radiation with a wavelength of 14.4 μm. Thus, in the section of the band from 177 to 1000 MHz the wavelengths of the synchrotron radiation and of

the waves which occur upon coherent movement of the beam may coincide and amplify one another to some extent [5].

In the absence of coherent vibrations of the beam the anticipated power of the synchrotron radiation equals $1.5 \cdot 10^{-9}$ W at E_i and 1.5 W with E_{max} of electrons.

A device which allows the recording of the electromagnetic waves with a frequency from 15 to 300 MHz was used in the first stage of the studies. An interference meter of the StG4-2 type (1 μV) has the highest sensitivity of all the instruments used.

A diagram of the experiments is shown in Fig. 1. A probe (1), and an electrostatic electrode (3) located inside the accelerating chamber and an antenna (4) which is moved around the betatron are used as sensors of the electromagnetic field. The inner end of the probe was moved out to the injection radius (r_i = 41 cm) and the electrode was located in a slightly larger radius. It is possible to use both a dipole with a variable length of the vibrators (at 30-230 MHz) as well as a broad-band antenna (60-300 MHz) with a circular radiation pattern as the antenna.

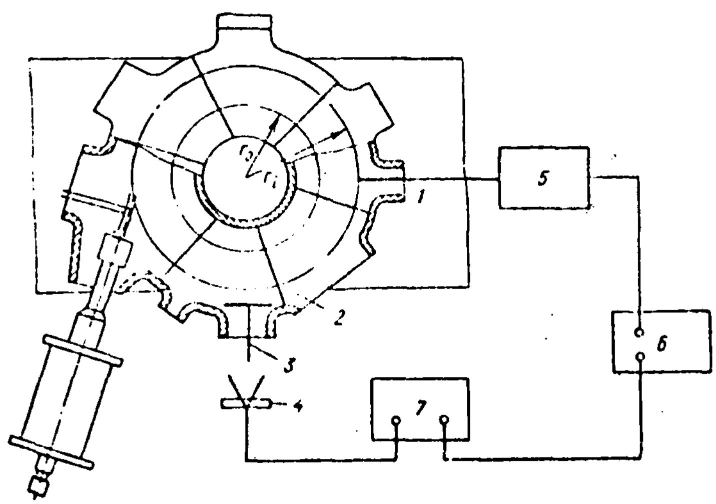

Fig. 1. A diagram of the experiments.

The signal from the probe (1) was fed into a broad-band amplifier (5) (URZ-3 or URZ-5) which has a pass band of from 5 to 250 MHz through a coaxial cable with a wave impedance of 75 Ω and with a length of 25 m. After the amplifier the signal may be fed either directly onto the plates of a dual-beam oscillograph (6) or detected and fed into one of the amplifiers of an oscillograph which has a narrower (up to 10 MHz) pass band. An oscillogram of two periods of the acceleration cycle which were repeatedly superimposed on each other during the course of which hf signals are generated is presented in Fig. 2.

The signals from the antenna (4) were fed into a radio reciever (7) through a coaxial cable and then into the second amplifier of the oscillograph (6). Thus, both the signals generated during acceleration as well as the signals of a 50-MHz frequency discriminated the radio-receiver (Fig. 3) were able to be observed simultaneously on the oscillograph screen. The electrostatic electrode (3) in this case was a spare sensor and was used for additional control and measuring the investigated signals' frequency with the help of a wavemeter.

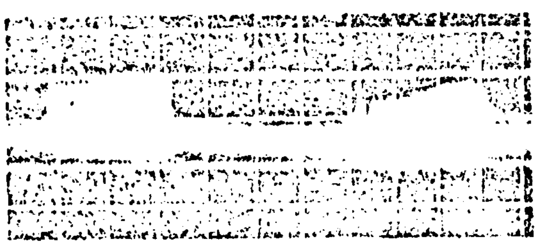

Fig. 2.

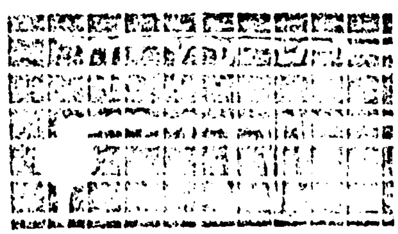

Fig. 3.

Fig. 2. The oscillograms of two acceleration periods.

Fig. 3. Signals during acceleration and from a radio reciever.

The following was established as a result of the conducted measurements. Electromagnetic radiation bears an individual nature and appears only in the course of several intervals of the acceleration cycle. In the course of one cycle generation may occur once or several times. Characteristic oscillograms of undetected amplified hf-signals taken from a CI-II oscillograph are presented in Fig. 4.

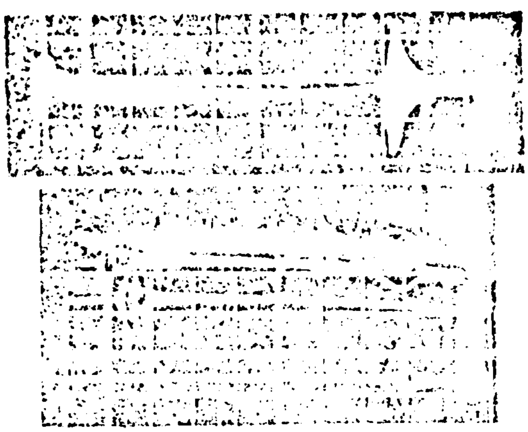

Fig. 4. An oscillogram of the initial stage of acceleration (a) and of a large number of acceleration cycles (b).

An oscillogram of the initial stage of one of the acceleration cycles is presented in Fig. 4a. Here, the origin of the sweep coincides with the moment of injection. One division of the coordinate grid corresponds to 20 μs. The generation in this cycle took place 160 μs after the end of the injection process. Oscillograms of a large number of acceleration cycles are presented in Fig. 4b. The origin of the sweep in these oscillograms is delayed by 140 μs in relation to the moment of injection. The oscillograms are obtained by the successive movement of the oscillograph's beam from top to bottom when operating in the mode of a driven sweep with a repetition frequency of 50 Hz. The oscillograms of more than ten acceleration cycles are superimposed on one another in the upper part of Fig. 4b, and three separate cycles are recorded below.

It can be seen that the moment of the hf signals' appearance varies from cycle to cycle. The earlier the moment of generation starts, the larger the signal's amplitude. In one of the cycles (the second sweep from the top) the generation occurred twice: at 160 and 300 μs.

Measuring the spectral composition of these pulses with the help of receivers showed that they contain frequencies which fall within the following ranges: 47-51 MHz, 53-55 MHz, 91-101 MHz, 103-109 MHz.

The "average" frequencies of the third and the fourth ranges are approximately twice as large as the "average" frequencies of the first and second ranges.

Measuring the field intensity with the help of a probe allowed establishing that the field intensity inside the accelerating chamber is significantly greater than outside, i.e., that the radiation appears inside the chamber and is weakened by the conductive covering. The field intensity inside an accelerating chamber attains 10 mV/m at frequencies of 47-51 MHz and 53-55 MHz and 1 mV/m at frequencies of 96-101 MHz and 103-109 MHz.

A qualitative connection between the value of the accelerated charge, the amplitudes of hf signals, and the beam's behavior was established. A gradual increase of the charge in orbit at first causes a proportional increase of the signals' amplitude. In this case the intensity at the accelerater's outlet also increases. Then a reduction of the intensity at the outlet by 20-30% sets in upon a certain value of current and upon the maximum amplitude of the hf signals. This means that upon generation of the hf field electrons are lost in the orbit. Control of the acceleration process with the help of a photomultiplier located near the acceleration chamber shows that it is indeed so. One acceleration cycle repeatedly superimposed on each other is shown in the oscillogram of Fig. 5. Signals of hf radiation are shown in the lower sweep and in the upper sweep - the losses accompanying it.

Closed circular paths burned out by electrons above and below the equilibrium orbit attest to the fact that electrons fall on the upper and lower walls of the accelerating chamber. A connection was established between the hf field's parameters and the pressure of the residual gas in the accelerating chamber. The pressure varied within limits of from $3 \cdot 10^{-6}$ to $4 \cdot 10^{-3}$ mm Hg, and here the working conditions of the accelerator and, specifically, the parameters of the injection system were not changed for the entire time of the experiment. The amplitude of the hf signals at first grows with the increase of pressure and the intensity on the accelerator's outlet

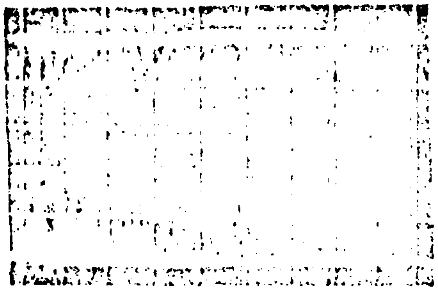

Fig. 5. One acceleration cycle repeatedly superimposed on each other.

slowly decreases. Then at p = $(3-4)\cdot 10^{-4}$ mm Hg the generation stops and the intensity at that moment increases with a sudden charge almost to the initial value with p = $3\cdot 10^{-6}$ mm Hg. The intensity at the accelerator's intake sharply drops with a further increase of the pressure and generation is no longer resumed. The influence of various devices placed inside the accelerating chamber and, in particular, of the coils of a magnetic deflector which occupies about 100° in azimuth and is used for a single-turn extraction of an electron beam on the accelerator was observed on the hf signals' amplitude. When a deflector is installed in the chamber the amplitude of the hf signals increases approximately by an order of magnitude.

Thus, hf fields may appear upon a presence of coherent dipole and quadrupole oscillations in the beam. The discovery of the intensity threshold attests to the fact that these oscillations start to cause a loss of particles upon a certain value of the current. The finite conductivity of the surrounding walls [2, 3] and of other dissipative elements placed inside the accelerating chamber may be the reason for the exciting of these oscillations.

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A SYSTEM OF ELECTRON BEAM EXTRACTION FROM AN ACCELERATING CHAMBER OF HIGH-CURRENT 25-MeV BETATRON

V. A. Moskalev, V. V. Shashov

Successes of recent years in increasing the intensity of a betatron's gamma-radiation made this accelerator even more promising for many purposes of practical application [1-5]. Electron beam extraction from a high-current betatron substantially widens the possibilities for its use.

A high-current 25-MeV betatron has a number of design features; an increased interpolar clearance; introducing injected electrons with the help of inflection plates sunk deeply into the accelerating chamber and located within the plane of the equilibrium orbit; a large radial dimension from the equilibrium orbit up to the boundary of the radial stability region and up to the outer wall of the chamber.

A two-stage method of extraction was suggested in connection with these design features. A preliminary widening of the orbit up to a radius somewhat smaller than the radius of the inflection plates' arrangement is accomplished initially with the help of a coil located on the central core. A generator of current pulses with an amplitude of up to 200 A and a duration of 280 μs [3] is used for powering the widening coil. The second stage consists of the single-turn extraction of the beam from the accelerating chamber from the initially widened orbit with the help of a pulsed magnetic deflector.

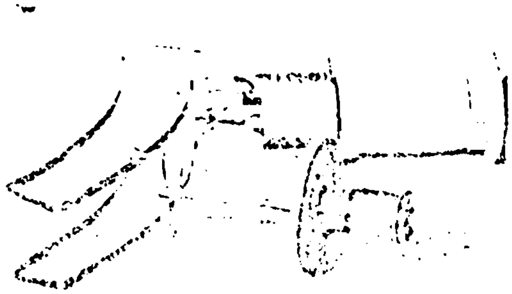


Fig. 1. The pulsed magnetic deflector.

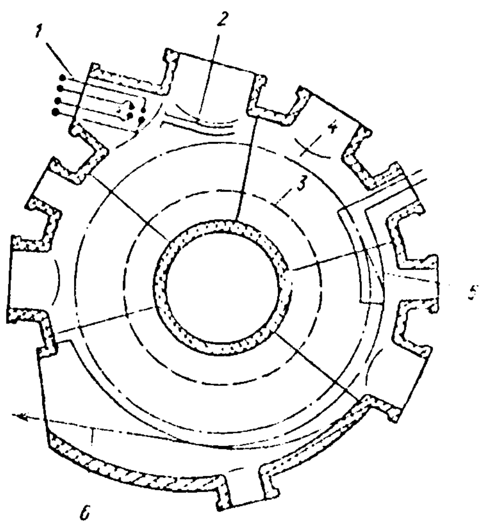


Fig. 2. The accelerating chamber: 1 - The injector; 2 - The inflector; 3 - The equilibrium orbit; 4 - The widened orbit; 5 - The deflector; 6 - The direction of the extracted beam.

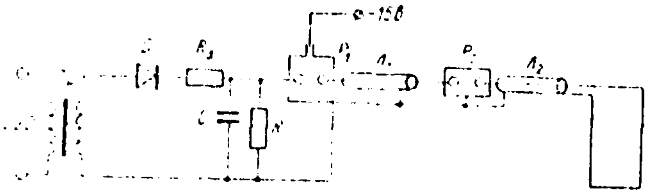
The pulsed magnetic deflector (Fig. 1) consists of two "squirrel-cage" lines, one of which is located higher than the median surface of the accelerator, the other - lower. The lines of a deflector are prepared from stainless steel plates with a thickness of 1.2 mm. The deflector's axial dimension equals 8.5 cm and the radial - 6 cm. A diagram of the deflector's position in an accelerating chamber is presented in Fig. 2. The angular extent of the deflector is 44^{o}. The inner edge of the deflector is installed at a radius of 36 cm. The azimuthal angle between the center of the outlet window and the deflector is about 130^{o}. The deflector's power is attained from a high-voltage nanosecond pulse generator (Fig. 3).

A gas-filled trigatron-type discharger P_1 with a trigger electrode made in the form of a toroid and located near the cathode is used as a commutator. The trigger electrode is not scorched because the operating current does not pass through it. A capacitor bank with a $5 \cdot 10^{-9}$ F capacitance assembled from K 15-4 capacitors serve an accumulator. It is charged from a half-wave single-phase rectifier made using D 1006 semi-conductor devices. The pulse's duration at the load (the deflector) is determined by the length of the forming coaxial line L_1 prepared from brass tubes and filled with transformer oil. A peaking discharger P_2 connected between the forming line and coaxial transmission line L_2 is used to obtain a pulse with a steep edge. The commutating and peaking dischargers are filled with nitrogen up to a pressure of 15 atm. The wave impedance of line L_2 equals 25Ω. Capacity dividers designed for switching on an oscillograph are installed on the forming and transmission lines.

The generator allows the obtainment of pulses with an amplitude of up to 100 kV, a duration of 13-15 ns and a 1-2-second build-up time of the front on the deflector. The generator operates stably with a frequency of up to 25 Hz. The electron beam with the following parameters:

The electrons' maximum kinetic energy	25 MeV
Number of electrons in the pulse	about $1.5 \cdot 10^{11}$
Duration of the radiation's pulse	5-6 ns
Beam's average current for prolonged operating time	0.6 μA
Current of the beam in the pulse	4.8 A
Beam's dimension at the outlet window:	
horizontal	6 cm
vertical	1.8 cm
The beam's angular divergence:	
in a horizontal direction	2°
in a vertical direction	1°
The electron beam bunch's length	1.5-1.8 m

is extracted from a high-current betatron's accelerating chamber with the help of the described devices.



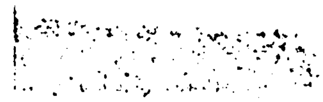


Fig. 3. Fig. 4.

Fig. 3. The generator's key diagram.

Fig. 4. A photograph of the beam.

The extracted beam was recorded with the help of a thin-walled ionization chamber with a volume of 0.3 cm^3. The beam's angular divergence in air is determined by direct exposure of photo paper under the beam at distances of 30 (Fig. 4) and 60 cm from the outlet window.

The number of extracted electrons was estimated approximately with the help of a comparison with the beam's known current at the exit of a regular (low-current) betatron with the same kinetic energies of the electrons (22 MeV). The average current of an electron beam extracted from a high-current betatron was two orders of magnitude higher.

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